

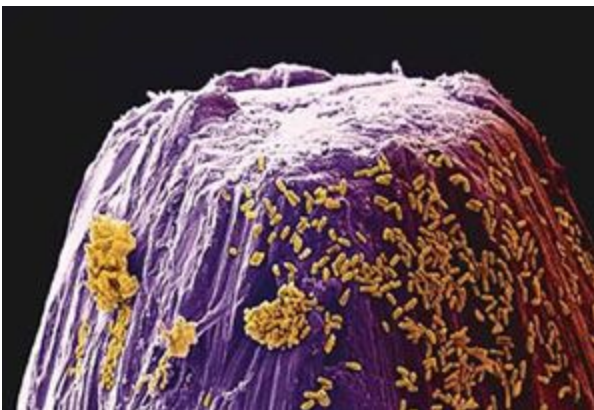
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01.0 Introduction to Bis2A

Introduction summary of the course Bis2A. This module discusses how Bis2A is taught, what study guides and learning goals are and some of the best study practices for doing well in Bis2A.

Welcome to Bis2A

Welcome to Biological Sciences 2A. BIS 2A is a 5-unit course with three 50min lectures plus a 2-hour discussion each week. BIS 2A is the first course in the Biological Sciences lower division core sequence. This sequence provides a foundation in modern biology for a broad range of majors. **This is not a survey course in biology.** In BIS2A, you will be introduced to the fundamental chemical, molecular, genetic, and cellular building blocks of living organisms and universal core concepts in biology. In BIS 2B, you will examine ecological and evolutionary processes that shape biological diversity. Finally in BIS 2C, you will examine biological diversity in detail. BIS2A is intended to provide you with foundational knowledge that you will build on in 2B and 2C and carry with you throughout your subsequent courses. We will stress important concepts, but will also expect you to learn some of the vocabulary of Biology. This should be fun!



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Some of your responsibilities

BIS2A is a team effort. Several professors were involved in developing the course content and syllabus. Please keep up with your responsibilities as a

student. Come to class prepared. Keep current on your studying. Seek out assistance immediately when you need it. If everyone in the class can conscientiously do these things, we'll all have fun this quarter (even while working hard) and be a happy and smarter bunch at the end of the term!

The main course learning objectives include:

1. Apply principles of chemistry and bioenergetics in the context of biological systems to describe how cells acquire and transform energy to fuel various life sustaining processes, including chemical transformations of elemental compounds, cellular replication, and cellular information processing.
2. Explain the relationship between genotype and key genetic processes that create phenotypic diversity.
3. Describe the processes regulating the management of cellular information; how information is stored, read, rearranged, replicated; how cells interact with their environment and how these processes can control cellular physiology.

Active Learning

In every lecture, we will ask you to answer questions, either in a small group or individually. To help you prepare for each lecture, we provide pre-lecture assignments that you should complete before coming to class. This will ensure that you are ready for discussions and that you can make the most of your time during class. We do not expect you to be an expert in the material before lecture, but I do expect you to make yourself familiar with the vocabulary and spend some time thinking about the concepts. We will build on that basic knowledge in lecture, and if you do not have the building blocks, you will have a hard time keeping up.

I cannot emphasize too strongly that **YOU have the primary responsibility for learning the material in this (or any other) course.** Although we are invested in your success, your instructors and TAs cannot magically implant knowledge. Like any other discipline that requires mastery (sports, music, dance, etc) we can help guide you and critique your performance but we can not replace the hours of practice necessary to become good at something. You would never expect to become a pianist by

going to lessons once or twice a week and never practicing. Likewise you can't just look at sheet music and expect to play it well without putting in time to practice moving your fingers. To most of us it seems self-evident that you need practice to become proficient at something like music, art, or sports. It's the same with learning biology or any other academic subject. We see ourselves as your coach for this class – we want to see you all succeed, but in order to get you there, we need you to take your practice seriously. This means coming to class prepared, participating in class, studying the material covered in class as soon as possible, identifying where you are uncertain and getting help to clarify those topics as soon as possible, and trying to make thoughtful contributions to the on-line discussions (not just the bare minimum required to "get the points").

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[Nota Bene](#) NB is an online resource for collaborative commenting and discussion. You will be required to contribute thoughtful comments, intelligent questions, or even answers to questions from your fellow classmates on selected readings. Your instructors will upload a variety of documents or provide html links to content for you to discuss as a class. The reading and discussion are intended to help you prepare for lecture, learn the core course concepts, and to develop the intellectual skills we expect from our students. **Assignments in NB will be graded and your score will depend on the quality of your contributions.**

As your instructors and TAs, we look forward to reading the NB threads that you will produce. We will add our own comments, flag misconceptions, and highlight particularly good or informative comments or threads. We hope that you'll find the feedback useful. These discussions also help us to

focus our limited time together in lecture on the content/skills that seem most confusing or difficult to master. As each class is slightly different, this will hopefully allow us to more effectively tailor lecture time for your needs.

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We hope that study guides can give you:

- A guide for targeted and structured studying (a suggested "what to do" list) that will help you practice and get a perspective on what the instructor thinks is important to know and master.
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The pre-lecture study guides list the:

- (a) learning goals for each lecture
- (b) the reading assignments
- (c) a vocabulary list we expect you to know
- (d) a set of self-tests of what you should be able to do before coming to lecture

The post-lecture study guides contain:

- (a) a variety of exercises that reinforce the mental muscles that are important for mastering the learning goals
- (b) model exam questions that model the kind of thinking that will be expected on the exam

It is important that you do the pre-lecture study guides before class and the post-lecture study guides as soon as you can after class. Use these documents to identify areas that you are having difficulty and seek help right away. Waiting to do these exercises until the last minutes defeats much of their purpose.

The course may ask many of you to flex and exercise different mental "muscles" than you are usually asked to work in other classes. We recognize this challenge and have designed the post-lecture study guides to help you with this task. The guides include a variety of exercises like instructions on creating vocabulary study lists, drawings, specific instructions to review lecture content (and often how to), example multiple choice questions that are formatted in exam style, and various other study aides. Some of the exercises may feel strange at first, but remember they're designed by the

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Once you're convinced that you have mastered the learning goals and have practiced/reinforced key concepts and skills using the study-guides we recommend that you practice by creating mock exam questions that are designed to test a fellow student's understanding of the learning goals.

Previous exam questions

Many students want previous exam questions to practice from. We get it and we include previous exam questions and exam-style questions on the post-lecture study guides. You may also be asked to work collaboratively on Nota Bene to answer previous exam questions.

However, please be advised that we have found that many students don't use these questions as effectively as they could. These are **NOT** meant to be exercises in memorization! Your instructor will not, in all likelihood, ask you the exact same question. Many students fall into a trap of using these questions as a last second study guide, cross-referencing with a key and mentally checking off that they understand a topic because the answer choice "makes sense". Beware, if you are falling into this trap, you likely have a false sense of the depth of your real understanding.

Rather, we think that the "right" way to use these questions is to study them by:

How to study previous exam questions effectively

- Asking yourself WHAT learning goal(s) this question is testing mastery of. Remember some questions may require you to integrate

learning goals.

- Asking yourself HOW the instructor is testing the learning goals you identified above. Points 1 and 2 are asking you to figure out what you needed to know or be able to do to answer the question and how did the instructor ask me to demonstrate this.
- Asking yourself how you can RECAST the question (changing some details or specifics) and still ask for the student to demonstrate mastery of the associated learning goals. We as instructors do this all the time.
- Asking yourself how you can CREATE a new question that an instructor could use to test the same learning goals. We as instructors do this all the time too.

Study habit and self testing

Over the years, your instructors have talked with many, many students to try and understand why some students are more successful than others. The picture is, as you might expect, complicated. However, there seem to be at least two habits that we can consistently associate with highly successful students and that we find are practiced much less frequently by students who struggle. These are:

Habits associated with highly successful BIS2A students

- Reviewing and studying material associated with a lecture THAT SAME DAY. This includes reviewing the lecture notes, vocabulary, and doing associated exercises. This ALSO includes making lists of concepts that still aren't clear and trying to have those questions cleared up before the following lecture.
- Constant self testing. That is, most successful students have developed methods (there are many) for assessing their comfort level with their understanding of the course material and spending more time on areas they find MOST challenging.

The first point is relatively easy to understand. Don't procrastinate. Material builds up quickly, concepts are often layered and exams sneak up on you very fast in the quarter system. It is difficult to identify the holes in your understanding of a topic and fill them appropriately two days before the exam.

The second point about self testing is more subtle. Basically, students that are good at this skill have ways of asking themselves "do I really understand the point of this question and the reason for the answer?" This can happen in a number of ways. We suggested one above. Try to invent new exam style questions for a concept or skill. Another good way to test yourself is to work in groups and force yourself to explain a topic or question to another student, as if you were the instructor. This is often more difficult than it seems. While this exercise can be hard - particularly if you are not used to flexing these mental muscles - this type of introspection is important to develop for both your short and long term success and we encourage you to look inward and test yourself and your understanding often when you are studying.

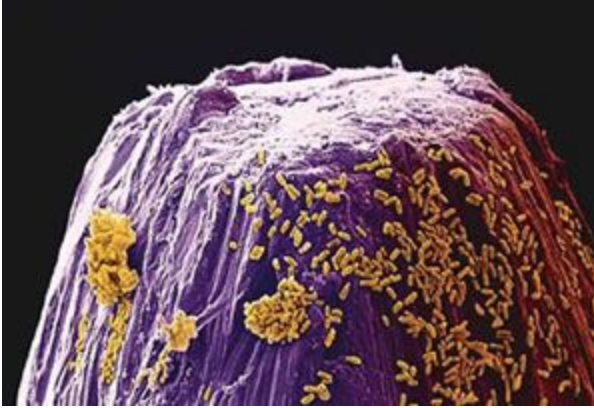
Lecture 1 SSI 2016 readings: Modules 01.0 to 01.4

In this module is an brief introduction to the topic of biology, some challenges associated with the teaching and learning of biology, and a very brief introduction to the scientific method. The discussion about teaching and learning challenges is meant to give students their instructor's perspective on some of the challenges associated with BIS2A and to explain how some of the methods used in class can help to make things easier. Finally, the discussion about the scientific method - while far from complete - is designed to make the highlight the way in which knowledge is built in biology and to provide some theoretical support for the development of healthy skepticism of scientific "fact".

Module 01.0

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Many students want previous exam questions to practice from. We get it and we include previous exam questions and exam-style questions on the

post-lecture study guides. You may also be asked to work collaboratively on Nota Bene to answer previous exam questions.

However, please be advised that we have found that many students don't use these questions as effectively as they could. These are **NOT** meant to be exercises in memorization! Your instructor will not, in all likelihood, ask you the exact same question. Many students fall into a trap of using these questions as a last second study guide, cross-referencing with a key and mentally checking off that they understand a topic because the answer choice "makes sense". Beware, if you are falling into this trap, you likely have a false sense of the depth of your real understanding.

Rather, we think that the "right" way to use these questions is to study them by:

How to study previous exam questions effectively

- Asking yourself WHAT learning goal(s) this question is testing mastery of. Remember some questions may require you to integrate learning goals.
- Asking yourself HOW the instructor is testing the learning goals you identified above. Points 1 and 2 are asking you to figure out what you needed to know or be able to do to answer the question and how did the instructor ask me to demonstrate this.
- Asking yourself how you can RECAST the question (changing some details or specifics) and still ask for the student to demonstrate mastery of the associated learning goals. We as instructors do this all the time.
- Asking yourself how you can CREATE a new question that an instructor could use to test the same learning goals. We as instructors do this all the time too.

Study habit and self testing

Over the years, your instructors have talked with many, many students to try and understand why some students are more successful than others. The picture is, as you might expect, complicated. However, there seem to be at least two habits that we can consistently associate with highly successful students and that we find are practiced much less frequently by students who struggle. These are:

Habits associated with highly successful BIS2A students

- Reviewing and studying material associated with a lecture THAT SAME DAY. This includes reviewing the lecture notes, vocabulary, and doing associated exercises. This ALSO includes making lists of concepts that still aren't clear and trying to have those questions cleared up before the following lecture.
- Constant self testing. That is, most successful students have developed methods (there are many) for assessing their comfort level with their understanding of the course material and spending more time on areas they find MOST challenging.

The first point is relatively easy to understand. Don't procrastinate. Material builds up quickly, concepts are often layered and exams sneak up on you very fast in the quarter system. It is difficult to identify the holes in your understanding of a topic and fill them appropriately two days before the exam.

The second point about self testing is more subtle. Basically, students that are good at this skill have ways of asking themselves "do I really understand the point of this question and the reason for the answer?" This can happen in a number of ways. We suggested one above. Try to invent new exam style questions for a concept or skill. Another good way to test yourself is to work in groups and force yourself to explain a topic or question to another student, as if you were the instructor. This is often more difficult than it seems. While this exercise can be hard - particularly if you are not used to flexing these mental muscles - this type of introspection is important to develop for both your short and long term success and we encourage you to look inward and test yourself and your understanding often when you are studying.

Module 01.1

Insert paragraph text here.

What is Biology?

Biology is the scientific study of life. Studying biology is an opportunity to ask exciting questions about the world that surrounds us. It is an

opportunity to dig into some of humanity's deepest questions about our own origins, the history of our planet, and our connections to other living beings (big and small/[extant](#) or [extinct](#)). It is also an opportunity to dive into a world of practical problem solving and to think hard about possible solutions for improving health care, maintaining sustainable food supplies, and producing renewable energy technologies.

The study of biology is also relevant to understanding issues and addressing problems we encounter every day. For instance, you can better understand how what you eat and the amount you exercise influence your health when you understand the biochemical reactions that describe how the food (matter) is transformed, how it and your body store energy, and how this energy can be transferred from the food to your muscles. Making the decision to buy products labeled with terms like "antimicrobial" or "probiotic" can be easier if you understand what the microbes, which live in, on, and around us, do. Understanding the biochemical principles that describe the changes that happen to eggs as they cook can help us to the understand cellular phenomena related to cellular stress response and disease processes. Your eye color can be better appreciated with an understanding of the genetic and biochemical mechanisms that link genetic information to physical traits.

The study of biology is also important for helping us understand things that may be literally out of this world. For instance, understanding the requirements for life can help us look for life in places like Mars or deep in the earth's crust. When we get an understanding of how to properly "rewire" cellular decision making networks we may finally be able to regenerate functional limbs or organs from someone's own tissue, or reprogram diseased tissues back to health. There are many exciting opportunities.

Note:**Possible Discussion**

What areas of biology that relate to your lifestyle/interests/etc. are you looking forward to understanding better?

Note:**Possible Discussion**

What everyday things have explanations whose roots can be traced to basic biology?

Biology: An interdisciplinary science

Questions in biology span size scales in excess of ten orders of magnitude, from the atomic make-up and chemical behavior of individual molecules to planetary-scale systems of interacting ecologies. Whatever the scale of interest, to develop a deep and functional understanding of biology we must first develop a keen appreciation for biological concepts. This involves integrating important ideas and tools from across the spectrum of scientific inquiry, including chemistry, physics, and mathematics. Biology is truly an interdisciplinary science.

The potential application of knowledge is broad

The study of biology leads to a vast number of applications that range from treating (human or other animal) patients in the health sciences, to creating improved agricultural practices, to the development of new building materials, to writing new energy policy, to helping craft solutions to global climate change, to creating new works of art - the list goes on and on. The study of biology can therefore lead to or influence many careers. It is not only about medicine, animals and plants. Biology also has plenty of mysteries left to explore.

As you go through your coursework, remember to keep an open mind and appreciate all of the exciting questions and topics biology has to offer. Even though they may not always seem related, take some time to find connections between topics covered in class and your current interests. You'll find that understanding how seemingly different topics are interrelated can give you a deeper appreciation for the things you enjoy and maybe even spark a new passion.

BIS2A - From molecules to cells

In BIS2A, our focus is on the cell, one of the most fundamental units of life. Cells can be as simple as those of the disease-causing bacterium *Mycoplasma genitalium* whose genome encodes just 525 genes (only 382 of which are essential for life) or as complex as a cell belonging to the multicellular plant *Oryza sativa* (rice) whose genome likely encodes ~51,000 genes. However, in spite of this diversity, all cells share some fundamental properties. In BIS2A, we explore the basic problems that must be dealt with by all cells. We study the building blocks of cells, some of their key biochemical properties, how biological information is encoded in genetic material, how it is expressed and how all this comes together to make a living system. We will also discuss some of the ways in which living systems exchange matter, energy and information with their environment (including other living things). We focus primarily on core principles that are common to all life on Earth and due to biology's breadth, we try to put these ideas into a variety of contexts throughout the quarter.

Get involved - Share with us short videos of: 1. Cool stuff students are doing on campus in biology. 2. Faculty highlighting what they think is cool. 3. Industrial partners that need people with good biology background. 4. Artists who merge biology with art. 5. Someone working in policy. 6. Other cool student-focused biology stories.

Learning and Knowledge

Teaching and Learning Science

Teaching and learning science are both challenging endeavors. As instructors, we need to communicate complex, highly interconnected concepts that will serve as a foundation for all your future studies. We also want our students to demonstrate mastery of these ideas at a high level. As students, you need to learn a large new vocabulary, create mental models on which you can "hang" the new conceptual knowledge, and figure out how to demonstrate that you can actually use this new knowledge. The process challenges both the instructor and the student. Although the process involves hard work, it can also be incredibly rewarding. There is nothing more satisfying for an instructor than those "Aha!" moments when a student suddenly understands an important concept.

In BIS2A we face some interesting teaching and learning challenges. One key challenge is that we discuss physical things and ideas that exist or happen on time and/or size scales that are not readily familiar to most students. What does this mean? Consider the following comparative example:

Example:

Some challenges associated with creating mental models

An instructor teaching wildlife biology may want to talk about concepts in evolution by using bird beaks as a starting point for discussion. In this case, the instructor does not need to spend time creating mental pictures of different shaped bird beaks (or at the very least only needs to show one image); most students will readily draw on their past knowledge and everyday lives to create mental pictures of duck, eagle, or wood pecker beaks and the different functional reasons why Nature might have selected different shapes. As a consequence, the students will not need to expend any mental effort imagining what the beaks look like and can instead focus all of their energies on the core evolutionary lesson.

By contrast, in BIS2A we ask students to think about and discuss things that happen on the atomic, molecular and cellular scales and at rates that span microseconds to millennia. The absence of mental models based on everyday or historical experience places an additional burden on both the student and the BIS2A instructors to create and reinforce NEW mental models for many of the things we talk about. For instance, to really talk about how proteins function, we first need to develop a set of models for representing molecules at the atomic and molecular levels. Not only do these models need to find ways of representing the molecule's structure, but the models must also contain abstract ideas about the chemical properties of molecules and how these molecules interact. Therefore, students in BIS2A need to put some effort into constructing mental models of what proteins "look" like and how they behave at the molecular scale. Since the entire course centers around biomolecules and processes that happen at a microscopic scale, a similar argument can be made for nearly every topic in the class.

Note:

Possible Discussion

What is a mental model? Why is it important for learning?

Some of the in-class and study guide exercises are designed to help with this; most students have found them very useful. However, some students are more accustomed to studying for exams by memorizing information rather than understanding it. (It's not their fault; that's what they were asked to do in the past). As a result, some of the BIS2A exercises may seem pointless. For instance, why are your instructors asking you to repeatedly draw some of the concepts described in class? What multiple-choice question could that exercise possibly prepare you for? While it is true that some of your instructors won't ask you to draw complicated figures on an exam, these drawing exercises are not trying to prepare students for one specific question. Rather the instructor is trying to encourage you to begin creating a mental model for yourself and to practice using it. **The act of drawing also serves as a "self test."** When you force yourself to write something down or to create a picture describing a process on paper, you will be able to independently assess how strong your conceptual grasp of a topic really is by seeing how easy or hard it was to put your mental image of something onto paper. If it is hard, it is likely that you need more practice. If it is easy, you are ready to add new information to your model. Throughout the course, you will continue to add new information to your mental model or to use the concept represented in your mental model in a new context.

Incidentally, the use of the concept, which the student is being asked to practice by drawing, in a NEW context on an exam, is not an evil plot by the instructor. Rather it is a way for the instructor and student to assess whether the concept has been learned and can be used/transferred by the student outside of the specific example in which it was initially presented. Asking the student to repeat the latter would represent an exercise in memorization and would not be an assessment of valuable learning and independent thinking or a representation of what happens in real life.

IMPORTANT: The idea that students in BIS2A will be tested on their ability to USE concepts in specific contexts that they haven't seen before is critical to understand! Take special heed of this knowledge. Developing usable conceptual knowledge takes more discipline and work than memorizing. The quarter also moves VERY fast and concepts are layered one on top of the other. If you get too far behind, it is very, very difficult to make up for lost time two or three days before an exam. Be as disciplined as you can and keep up with course materials.

So, some concepts are hard to teach and to understand. What are we to do? Something instructors and students both do is to use various communication tricks to simplify or make abstract ideas more relatable. We use tools like [analogies](#) or simplified models (more on the importance of these shortly) to describe complex ideas. Making things more relatable can take various forms. Instructors might try to use various [similies](#) or [metaphors](#) to take advantage of mental pictures or conceptual models that students already have (drawn from everyday life) to explain something new. For instance, the thing X that you don't understand works a little like thing Y that you do understand. Sometimes, this helps ground a discussion. Another thing you might catch an instructor or student doing is [anthropomorphizing](#) the behaviors of physical things that are unfamiliar. For example we might say molecule A “wants” to interact with molecule B to simplify the more correct but more complex description of the chemical energetics involved in the interaction between molecules A and B. Anthropomorphisms can be useful because, like similes and metaphors, they attempt to link the creation of new ideas and mental models to concepts that already exist in the student's brain.

While these tools can be great and effective they nevertheless need to be used carefully - by both the instructor and the student. The main risk associated with these simplifying tools is that they can create conceptual connections that shouldn't exist, that lead to unintended misconceptions, or that makes it more difficult to connect a new concept. So while these tools are valid, we - students and instructors - also need to be vigilant about understanding the limits these tools have in our ability to learn new ideas. If these [pedagogical](#) tools are useful but their use also carries risk, how do we

proceed?

The remedy has two parts:

1. Recognize when one of these "simplifying" tools is being used and
2. Try to determine where the specific analogy, metaphor etc. works and where it fails conceptually.

The second instruction is the most difficult and may prove challenging for learners, particularly when they are first exposed to a new concept. However, the act of simply thinking about the potential problems associated with an analogy or model is an important [metacognitive](#) exercise that will help students learn. In BIS2A your instructors will occasionally expect you to explicitly recognize the use of these pedagogical tools and to explain the trade-offs associated with their use. Your instructors will also help you with this by explicitly pointing out examples or prodding you to recognize a potential issue.

Note:

Possible discussion

Can you give an example from your previous classes where an instructor has used an anthropomorphism to describe a nonhuman thing? What were/are the trade-offs of the description (i.e. why did the description work and what were its limitations)?

The use of vocabulary

It is also worth noting another problematic issue that can needlessly confound students just starting out in a discipline - the use of vocabulary terms that potentially have multiple definitions and/or the incorrect use of vocabulary terms that have strict definitions. While this is not a problem unique to biology, it is nevertheless important to recognize that it occurs. We can draw from real-life examples to get a better sense of this issue. For instance, when we say something like "I drove to the store", a couple of

things are reasonably expected to be immediately understood. We don't need to say "I sat in and controlled a four-wheeled, enclosed platform, that is powered by the combustion of fossil fuel to a building that collects goods I want to obtain and can do so by exchanging [fungible](#) currency for said goods" to convey the core of our message. The downside to using the terms "drove" and "store" is that we have potentially lost important details about what really happened. Perhaps the car is battery powered and that is important to understanding some detail of the story that follows (particularly if that part of the story involves calling a tow truck driver to pick you up after the car has broken down). Perhaps knowing the specific store is important for understanding context. Sometimes those details don't matter, but sometimes if they aren't known it can lead to confusion. Using vocabulary correctly and being careful about word choice is important. Knowing when to simplify and when to give extra detail is also key.

Note:In the laboratory, undergraduate students in biology will often report back to their mentors that "my experiment worked" without sharing important details of what it means to have "worked", what the evidence is, how strong the evidence is, or what the basis is for their judgment - all details that are critical to understanding exactly what happened.

Note:

Possible discussion

Can you think of an example where the imprecise or incorrect use of vocabulary caused needless confusion in real life?

In class, we will learn new terminology - much of it is intended to save us from over-describing. Some of the terms/vocabulary we will use have very strict definitions; we need to learn these definitions and use them when appropriate. Other terms like "gene" may have more ambiguous definitions and are still debated in some circles. We need to learn to recognize the more ambiguous terms and be ready to provide a definition of what we mean

before we use the term in context or to be ready to ask for clarification if the use of the term seems too ambiguous. Unfortunately, the loose use of some terms also leads to building incorrect conceptual frameworks and this must be avoided. As instructors we work hard to avoid misusing terms or taking too many potentially confusing shortcuts. As students it is your responsibility to learn the assigned vocabulary in a timely manner. This is not because you will be asked on a test to identify the correct definition but rather because we need to use it in class to construct lessons and concepts. Exams will expect that you can recognize the terms in context and make appropriate inferences from that meaning. The suggestions on your study guides to make a running list of vocabulary terms before and after class and to practice using them in context are meant to stress this idea. Trying to memorize terms a couple of days before the exam without having used them in class or in studying will not help you to use them properly in context or on the exam.

The Scientific Method

The Scientific Method

An example of oversimplification that confounds many students of biology (particularly early in their studies) is the use of language that hides the experimental process used to build knowledge. For the sake of expediency we often tell stories about biological systems as if we are presenting unquestionable facts. However, while we often write and speak about topics in biology with a conviction that gives the appearance of "factual" knowledge, reality is often more nuanced and filled with significant uncertainties. The "factual" presentation of material (usually lacking discussion of evidence or confidence in the evidence) plays to our natural tendency to feel good about "knowing" things but it tends to create a false sense of security in the state of knowledge and does little to encourage the use of imagination or the development of critical thinking. A better way to describe our knowledge about the natural world would be to explicitly qualify that the knowledge presented represents our current best understanding that has not yet been refuted by experiment. Unfortunately, repeated qualification becomes rather cumbersome. **The important thing to remember is that while we may not say so explicitly, all of the knowledge we discuss in class represents only the best of our current**

understanding. Some ideas have withstood repeated and varied experimentation while other topics have yet to be tested as thoroughly.

So if we're not as certain about things as we'd like to believe sometimes, how do we know what to put confidence in and what to be skeptical of? The complete answer is non-trivial but it begins with developing an understanding of the **process** we use in science to build new knowledge. The scientific method is the process by which new knowledge is developed. While the process can be described with long lists of "steps" (often seen in textbooks) its core elements can be described more succinctly.

Succinct Description of Scientific Method (adapted from [Feynman](#))

1. Make an observation about the world.
2. Propose a possible explanation for the observation.
3. Test the observation by experiment.
4. If the observation disagrees with experiment, the observation is wrong.

At its core, that's it! In science there may be multiple proposed explanations or ideas that are tested by experiment. The ideas that fail experiment are left behind. The ideas that survive experiment move forward and are often retested by alternative experiments until they too either fail or continue to be retained.

Making an observation and asking a question

The ability to make useful observations and/or ask meaningful questions requires curiosity, creativity and imagination – this cannot be over-stated. Indeed, historically, it is first and foremost the application of these skills, perhaps more than technical ability, which has led to big advances in science. Many people think that making meaningful observations and asking useful questions is the easiest part of the scientific method. This is not always the case. Why? Seeing what others have not and being creative takes work and thoughtful reflection! In addition, our senses of observation are often biased by life-experience, prior knowledge, or even our own biology. These underlying biases influence how we see the world, how we interpret what we see, and what we are ultimately curious about. This means that when we look at the world, we can miss a lot of things that are actually right under our noses. Douglas Adams, who is best known for his book entitled *The Hitchhiker's Guide to the Galaxy*, once expanded on this

point by writing:

“The most misleading assumptions are the ones you don't even know you're making.”

Scientists, therefore, need to be aware of any underlying biases and any assumptions that may influence how they internalize and interpret observations. This includes approaching our bias that the variety of places we get our knowledge (i.e. textbooks, instructors, the Internet) are representing the absolute truth with a healthy dose of skepticism. We need to learn to examine the evidence underling the “facts” we supposedly know and make critical judgments about how much we trust that knowledge. More generally, taking the time to make careful observations and to uncover any assumptions and biases that could influence how they are interpreted is, therefore, time well spent. This skill, like all others, needs to be developed and takes practice and we'll try to start you on this in BIS2A.

For fun, and to test your observation skills, Google “observation tests”. Many of the search results will take you to interesting psychological tests and or videos that illustrate how difficult accurate observation can be.

Note:

Possible discussion -

Remember the example of “I drove to the store” that was presented earlier in this chapter. Can you think of any underlying biases or assumptions that might get in the way of your accurately describing a situation? How might they have impacted your observation?

Generating a testable hypothesis

The "possible explanation" referred to in step 3 above has a formal name; it is called a [hypothesis](#). A hypothesis is not a random guess. A hypothesis is an educated (based on prior knowledge or a new viewpoint) explanation for an event or observation. It is typically most useful if a scientific hypothesis can be tested. This requires that the tools to make informative

measurements on the system exist and that the experimenter has sufficient control over the system in question to make the necessary observations.

Most of the time, behaviors of the system that the experimenter wants to test can be influenced by many factors. We call the behaviors and factors, dependent and independent variables, respectively. The dependent variable is the behavior that needs explaining while the independent variables are all of the other things that can change and influence the behavior of the dependent variable. For example, an experimenter that has developed a new drug to control blood pressure may want to test whether her new drug actually influences blood pressure. In this example, the system is the human body, the dependent variable might be blood pressure, and the independent variables might be other factors that change and influence blood pressure like age, sex, and levels of various soluble factors in the blood stream.

Once the variables in the system are identified the experimenter starts by generating two complementary hypotheses: the null hypothesis and the alternative hypothesis. The alternative hypothesis is a statement that describes what the experimenter believes is the relationship between the dependent variable and one or more of the independent variables. In the blood pressure example the hypothesis might be: the presence of the drug in a person's body induces a change in blood pressure. By contrast the null hypothesis is a statement that would be true if the alternative hypothesis is false. In the blood pressure experiment, the experimenter might state that her null hypothesis is: that the presence of the drug in a person's body has NO effect on blood pressure.

Why bother with the null hypothesis? Why not just directly test the explanation that you think is true. The problem is that a well-designed experiment can only disprove a hypothesis. It is not possible to design an experiment that provides absolute proof that a hypothesis is correct. Therefore, in the blood pressure example, if the experimenter designs a study that disproves the null hypothesis – that is, the experimenter shows that the presence of the drug in a person's body leads to a measurable change in blood pressure, she has disproven her null hypothesis leaving her alternative hypothesis as best alternative explanation of the relationship between the drug and blood pressure. Note in this example, the experiment

has not determined why or how the blood pressure changed it was only determined that presence of the drug does not lead to no change in blood pressure. The details of why or how must be investigated with additional experiments.

Note:In BIS2A, and beyond, we prefer to avoid using language like “the experiment proved her hypothesis” when referring to a case like the blood pressure example above. Rather we would say, “the experiment is consistent with her hypothesis.” Note that for convenience (one of the language shortcuts we discussed earlier) we referred to the alternative hypothesis simply as “her hypothesis”! It would be more correct to state, “the experiment falsified her null hypothesis and is consistent with her alternative hypothesis.” Why take this shortcut? Doing so adds confusion when a student is trying to learn. In this case, it was done to illustrate the point above about language shortcuts and hence the lengthy explanation. However, be aware of this commonly used shortcut and learn to make sure you can read in the correct meaning yourself.

Note:

Possible Discussion

What does the statement about falsifying hypotheses mean in your own words? Why is falsification critical to the scientific method?

Controls

In an ideal case, an experiment will include what are known as controls groups. Control groups are experimental conditions in which the values of the independent variables (there may be more than one) are maintained as close to those in the experimental group with the exception of the independent variable being tested. In the blood pressure example, an ideal scenario would be to have one identical group of people taking the drug and another group of people identical to those in the experimental group taking a pill containing something known to not influence blood pressure. In this

oversimplified example, all independent variables are identical in the control and experimental groups with the exception of the presence or absence of the new drug. Under these circumstances, if the value of the dependent variable (blood pressure) of the experimental group differs from that of the control group, one can reasonably conclude that the difference must be due to the difference in independent variable (the presence/absence of the drug). This is, of course, the ideal. In real life it is impossible to conduct the proposed drug dosage experiment; the variability of independent variables in a group of potential patients would be high. Fortunately, while statisticians have come to the rescue, you won't need to understand the nuances of these statistical issues in BIS2A.

Accuracy in Measurement, Uncertainty, and Replication

Finally, we mention the intuitive notion that the tools used to make the measurements in an experiment must be reasonably accurate. How accurate? They must be accurate enough to make measurements with sufficient certainty to draw conclusions about whether changes in independent variables actually influence the value of a dependent variable. If we take, yet again, the blood pressure example above, we made the assumption that the experimenter had tools that allowed her to make accurate measurements of the changes in blood pressure associated with the effects of the drug. For instance if the changes associated with the drug ranged between 0 and 3 mmHg and her meter capably measured changes in blood pressure with a certainty of ± 5 mmHg she could not have made the necessary measurements to test her hypothesis or would have missed seeing the effect of the drug. For the sake of example, we assume that she had a better instrument and that she could be confident that any changes she measured were indeed differences due to the drug treatment and that were due to measurement error, sample-to-sample variability, or other sources of variation that lower the confidence of the conclusions that are drawn from the experiment.

The topic of measurement error leads us to mention that there are numerous other possible sources of uncertainty in experimental data that you as students will ultimately need to learn about and that have a lot to do with determining how certain we are that certain experiments have disproven hypothesis, how much we should trust the interpretation of the experimental

results and by extension our current state of knowledge. Even at this stage, you will recognize some experimental strategies used to deal with these sources of uncertainty (i.e. making measurements on multiple samples; creating replicate experiments). You will learn more about this in your statistics courses later on. For now, you should, however, be aware that experiments carry a certain degree of confidence in the results and that the degree of confidence in the results can be influenced by many factors. Developing healthy skepticism involves, among other things, learning to assess the quality of an experiment and the interpretation of the findings and learning to ask questions about things like this.

Note:

Really good discussion and exam prep -

After moving to California to attend UC Davis, you have fallen in love with fresh tomatoes. You decide that the tomatoes in the stores just don't taste right and resolve to grow your own.

You plant tomato plants all over your back yard; every free space now has a freshly planted tomato seedling of the same variety. You have planted tomatoes in the ground in full sunlight and next to your house in full shade. After the first year of harvest, you make the observation that the plants growing in full shade almost always seem shorter than those in the full sun. You think that you have a reasonable explanation (hypothesis) for this observation.

Based on the information above, you create the following hypothesis to explain the differences in height you noticed in your tomatoes:

Hypothesis: The height that my tomato plants reach is positively correlated to the amount of sunlight they are exposed to (e.g. the more sun the plant gets the taller it will be).

This hypothesis is testable and falsifiable. So, the next summer you decide to test your hypothesis.

This hypothesis also allows you to make a prediction. In this case you might predict that IF you were to shade a set of tomatoes in the sunny part of the yard, THEN those plants would be shorter than their full-sun neighbors.

You design an experiment to test your hypothesis by buying the same variety of tomato that you planted the previous year and plant your whole yard again. This year, however, you decide to do two different things:

- (a) You create a shade structure that you place over a small subset of plants in the sunny part of your yard.
- (b) You build a contraption with mirrors that redirects some sunlight onto a small subset of plants that are in the shady part of the yard.

Question 1: We used a shortcut above. Can you create statements for both the null and alternative hypothesis? Work with your classmates to do this.

Question 2: Why do you create a shade structure? What is this testing? Based on your hypothesis what do you predict will happen to the plants under the shade structure?

Question 3: Why do you create the mirror contraption? Why do you potentially need this contraption if you already have the shade structure?

New Data: At the end of the summer you measure the height of your tomato plants and you find once again that the plants in the sunny part of the yard are indeed taller than those in the shady part of the yard. However, you notice that there is no difference in height between the plants under your shade structure and those right next to the structure in full sun. In addition, you notice that the plants in the shady part of the yard are all about the same height, including those that had extra light shined on them via your mirror contraption.

Question 4: What does this experiment lead you to conclude? What would you try to do next?

Question 5: Imagine an alternative scenario in which you discovered, as before, that the plants in the sunny part of the yard were all the same height (even those under your shade structure) but that the plants in the shady part of the yard that got “extra” light from your mirror contraption grew taller than their immediate neighbors. What would this say about your alternate hypothesis? Null hypothesis? What would you do next?

Question 6: What assumptions are you making about the ability to make measurements in this experiment? What influence might these assumptions have on your interpretation of the results?

In this class you will occasionally be asked to create a hypotheses, to interpret data, and to design experiments with proper controls. All of these skills take practice to master, we can start to practice them in BIS2A. Again, while we don’t expect you to be masters after reading this text, we will assume that you have read this text during the first week and that the associated concepts are not completely new to you. You can always return to this text as a resource to refresh yourself.

Disclaimer:

While the preceding treatment of the experimental method is very basic - you will undoubtedly add numerous layer of sophistication to these basic ideas as you continue in your studies – it should serve as a sufficient introduction to the topic for BIS2A. **The most important point to remember from this section is that the knowledge represented in this course, while sometimes inadvertently represented as irrefutable fact, is really just the most current hypothesis about how certain things happen in biology that has yet to be falsified via experiment.**

Module 01.2

Matter and Energy in Biology

Matter and Energy

The concepts of matter and energy are essential to all scientific disciplines, yet, while ubiquitous and fundamental, these concepts are often amongst the most confounding for students. Take the concept of energy. The term is used in a variety of contexts in everyday life - “Can we move the couch tomorrow? I don’t have the energy.” “Hey dude! Turn the light off. We need to conserve energy.” “This is a great energy drink.” In many sciences classes, students are told that energy comes in different forms (i.e. kinetic, thermal, electrical, potential, etc.), making it difficult to understand exactly what energy “is”. In class, the concept of energy is also associated with a myriad of different equations, each with different variables, but that somehow all seem to end up having units of work. Hold on! Work? I thought we were talking about energy?! Given all the different contexts and sometimes seemingly contradictory treatments and definitions, it’s not hard to understand why these topics seem challenging for many students and in some cases end up turning them off of the fields that make heavy use of these ideas. While the concepts of matter and energy are most often associated with chemistry and physics, they are nevertheless central ideas in biology and we don’t shy away from this in BIS2A. Our instructional goals, however, are to help students develop a conceptual framework that will help them use the concepts of matter and energy to:

- successfully describe biological reactions and transformations;
- create models and hypotheses for “how things work” in biology that explicitly include matter and energy and;
- be scientifically correct and transferable to new problems and to other disciplines.

While there may be a couple of energy-related equations to learn and use in BIS2A, the main focus of the course will be on the robust development of the concepts of energy and matter and their use in the interpretation of biological [phenomena](#).

Motivation for Learning About Matter and Energy

Discussions about matter and energy make many, but not all, BIS2A students a little apprehensive. After all, aren’t these topics that belong in chemistry or physics? However, the transformations of matter and energy transfer are not phenomena reserved for the chemists and physicists or even

scientists and engineers more generally. Understanding, conceptualizing, and doing some basic accounting of the transformations of matter and transfers of energy are fundamental skills regardless of occupation or academic training. The scientist may need more rigorous and systematic descriptions of these transformations than the artist but both make use of these skills at various points of their personal and or professional lives. Take the following examples:

Example: Matter and Energy Transformation in Global Warming

Let us for a moment consider a topic that affects us all, global warming. At its core lies a relatively simple model that is based on our understanding of energy in solar radiation, the transfer of this energy with matter on the Earth, and the role and cycling of key carbon containing gases in the Earth's atmosphere. In simple terms solar energy hits the earth and transfers energy to its surface, heating it. Some of this energy is transferred back into space. However, depending on the concentration of carbon dioxide (and other so-called greenhouse gases) different amounts of this energy may become “trapped” in the Earth’s atmosphere. Too little carbon dioxide and relatively little energy/heat is trapped - the Earth freezes and becomes inhospitable for life. Too much carbon dioxide and too much heat is trapped - the Earth overheats and becomes inhospitable for life. It stands to reason, therefore, that mechanisms (biological or other) that influence the levels of carbon dioxide in the atmosphere may be important to consider in the story of global warming and that developing a good understanding of global warming phenomena requires one to trace the flow of the carbon and oxygen (matter) through their different forms and the mechanisms by which energy is transferred to and from different components of the system.

Example: Muscle Contraction

Let us now consider a more personal example, the flexing of an arm starting from an extended position and ending in a flexed position. Like most processes, this one can be described and understood at various levels of detail: from the anatomical point of view where the system consists of muscles, skin, and bones to the molecular where the system is composed of individual interacting biomolecules. At whatever level of detail, if we want to create a story describing this process we know that: (a) the description must include an accounting for what happened to the matter in the system (this includes the change in position of the molecules making up the various parts of the arm and the fuel “burned” to move it) and (b) that some fuel was burned to initiate the movement and therefore, that any description of the process must also include an accounting change in the energy of the system. In simpler terms, this is really just saying that if you want to describe a process where something has happened, you need to describe what happened to the “stuff” in the system and what happened to the energy in the system to make the process happen.

We can't possibly cover all examples of matter and energy transfer in BIS2A. But, we will explore these issues often and practice describing transformations that happen in Nature with a structured and explicit attention to what is happening to the matter and energy in a system as it changes. We will do this exercise across different structural levels in biology, from the molecular level (like a single chemical reaction) to more large-scale and abstracted models like nutrient cycling in the environment. We will practice this skill by using a [pedagogical](#) tool we call “The Energy Story”. Be prepared to participate!

The Energy Story**Overview of the Energy Story**

Whether we know it or not, we tell stories that involve matter and energy everyday, we just don't often use terminology associated with scientific discussions of matter and energy.

Example:

The setup: a simple statement with implicit details

You tell your roommate a story about how you got to campus by saying, "I biked to campus today". In this simple statement are several assumptions that are instructive to unpack, even if they may not seem very critical to include explicitly in a casual conversation between friends over transportation choices.

An outsider's reinterpretation of the process

To illustrate this, imagine an external observer, for instance an alien being watching the comings and goings of humans on earth. Without the benefit of knowing much of the implied meanings and reasonable assumptions that are buried in our language, the alien's description of the morning cycling trip would be quite different than your own. What you described efficiently as "biking to campus" might be more specifically described by the alien as a change in location of a human body and its bicycle from one location (the apartment, termed position A) to a different location (the university, termed position B). The alien might be even more abstract and describe the bike trip as the movement of matter (the human body and its bike) between an initial state (at location A) to a final state (at location B). Furthermore, from the alien's standpoint what you'd call "biking" might be more specifically described as the use of a two-wheeled tool that couples the transfer of energy from the electric fields in chemical compounds to the acceleration of the two-wheeled tool-person combo and heat in its environment. Finally, buried within the simple statement describing how we got to work is also the tacit understanding that the mass of the body and bike were conserved in the process (with some important caveats we'll look at in future lectures) and that some energy was converted to enable the movement of the body from position A to position B.

Note: **Possible discussion:** Details are important. What if you owned a fully electric bike and the person you were talking with didn't know that? What important details might this change about the "everyday" story you told that the more detailed description would have cleared up? How would the alien's story have changed? In what scenarios might these changes be relevant?

As this simple story illustrates, irrespective of many factors the process of creating a full description of a process includes some accounting of what happened to the matter, what happened to the energy and almost always some description of a mechanism that describes how changes in matter and energy of a system were brought about.

To practice this skill, in BIS2A we will make use of something we like to call "The Energy Story". You may be asked to tell an energy story in class, to practice telling energy stories on your post or pre lecture study guides, and to use the concept on your exams. In this section, we focus primarily on introducing the concept of an energy story and explaining how to tell one. It is worth noting that the term "energy story" is used almost exclusively in BIS2A (and has a specific meaning in this class). This precise term will not appear in other courses at UC Davis (at least in the short term) or if it appears, is not likely to be used in the same manner. You can think of "The Energy Story" as a systematic approach creating a statement or story describing a biological process or event. Your BIS2A instructors have given this approach a short name "energy story," so that we can all associate it with the common exercise. That way when the instructor asks the class to tell or construct an energy story everyone knows what is meant.

Energy Story

An energy story is a narrative describing a process or event. The critical elements of this narrative are:

1. Identifying at least two states (e.g. start and end) in the process.

2. Identifying and listing the matter in the system and its state at the start and end of the process.
3. Describing the transformation of the matter that occurs during the process.
4. Accounting for the “location” of energy in the system at the start and end of the process.
5. Describing the transfer of energy that happens during the process.
6. Identifying and describing mechanism(s) responsible for mediating the transformation of matter and transfer of energy.

A complete energy story will include a description of the initial reactants and their energetic states as well as a description of the final products and their energetic states after the process or reaction is completed.

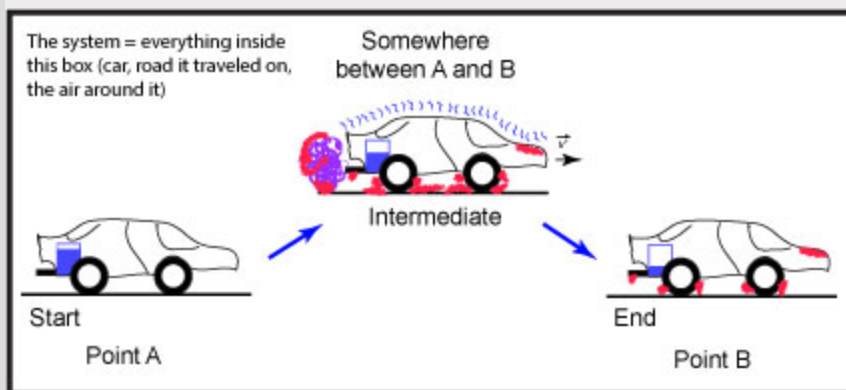
Note:Possible discussion: We argue that the energy story can be used to communicate all of the useful details that are required to describe nearly any process. Can you think of a process that cannot be adequately described by an energy story? If so, describe such a process.

Example:

Energy Story Example

Let us suppose that we are talking about the process of driving a car from "Point A" to "Point B" (see the figure).

A Car Moves from Point A to Point B



A schematic of a car moving at the start from position "Point A" to position "Point B" at the end. The blue rectangle depicted in the back of the car represents the level of gasoline, the purple squiggly line near the exhaust pipe represents the exhaust, squiggly blue lines on top of the car represent sound vibrations and the red shading represents areas that are hotter at the start.

Source: Created by Marc T. Facciotti (Own work)

Let's step through the Energy Story [rubric](#):

1. Identifying at least two states (e.g. start and end) in the process.

In this example we can easily identify two states. The first state is the non-moving car at "Point A", the start of the trip. The second state, after the process is done, is the non-moving car at "Point B".

2. Identifying and listing the matter in the system and its state at the start and end of the process.

In this case we first note that the "system" includes everything in the figure - the car, the road, the air around the car etc.

It is important to understand that we are going to apply the physical law of conservation of matter. That is, in any of the processes that we will discuss, matter is neither created or destroyed. It might change form, but one should be able to account for everything at the end of a process that was there at the beginning.

At the beginning of the process, the matter in the system consists of:

1. The car and all the stuff in it
2. The fuel in the car (a special thing in the car)

3. The air (including oxygen) around the car.
4. The road
5. The driver

At the end of the process, the matter in the system is distributed as follows:

1. The car and all the stuff in it is in a new place (lets assume, aside from the fuel and position, that nothing else changed)
2. There is less fuel in the car and it too is in a new place
3. The air has changed - it now has less molecular oxygen, more carbon dioxide and more water vapor.
4. The road (let's assume it didn't change - other than a few pebbles moved around)
5. The driver (let's assume she didn't change - though we'll see by the end of the term that she did (at least a little). But, the driver is now in a different place.

3. Describing the transformation of the matter that occurs during the process.

What happened to the matter in this process? Thanks to a lot of simplifying assumptions, we see that two big things happened. First, the car and its driver changed positions - they went from "Point A" to "Point B". Second, we note that the molecules in the fuel, which used to be in the car as a liquid has changed forms and is now mostly in the form of carbon dioxide and water vapor (purple blob coming out the tailpipe). The oxygen molecules that used to be in the air are now also in a new place as part of the carbon dioxide and water that left the car.

4. Accounting for the “location” of energy in the system at the start and end of the process.

It is again important to understand that we are going to invoke the physical law of conservation of energy. That is, we stipulate that the energy in the system cannot be created or destroyed and therefore the energy that is in the system at the start of the process must still be there at the end of the process. It may have been redistributed but you should be able to account for all the energy.

At the beginning of the process, the energy in the system is distributed as follows:

1. The energy tied up in the associations between atoms that make up the matter of the car.
2. The energy tied up in the associations between atoms that make up the fuel.
3. The energy tied up in the associations between atoms that make up the air.
4. The energy tied up in the associations between atoms that make up the road.
5. The energy tied up in the associations between atoms that make up the driver.
6. For all things above we can also say that there is energy in the molecular motions of the atoms that make up the stuff.

At the end of the process, the energy in the system is distributed as follows:

1. The energy tied up in the associations between atoms that make up the matter of the car.
2. The energy tied up in the associations between atoms that make up the fuel.
3. The energy tied up in the associations between atoms that make up the air.
4. The energy tied up in the associations between atoms that make up the road.
5. The energy tied up in the associations between atoms that make up the driver.
6. For all things above we can also say that there is energy in the molecular motions of the atoms that make up the stuff.

This is interesting in some sense because the lists are about the same. We know that the amount of energy stored in the car has decreased because there is less fuel. Something must have happened.

5. Describing the transfer of energy that happens during the process.

In the particular example it is the transfer of energy about the components of the system that is most interesting. As we mentioned, there is less energy stored in the gas tank of the car at the end of the trip because there

is now less fuel. We also know intuitively (from our real life experience) that the transfer of energy from the fuel to something else was instrumental in moving the car from "Point A" to "Point B". So, where did this energy go? Remember, it didn't just disappear. It must have moved somewhere else in the system.

Well we know that there is more carbon dioxide and water vapor in the system after the process. There is energy in the associations between those atoms (atoms that used to be in the fuel and air). So some of the energy that was in the fuel is now in the exhaust. Let's also draw from our real life experience again and state that we know that parts of our car have gotten hot by the end of the trip (e.g. the engine, transmission, wheels/tires, exhaust etc.). For the moment we'll just tap our intuition and say that we understand that making something hot involves some transfer of energy. So we can reasonably postulate that some of the energy in the fuel went (directly or indirectly) into heating the car, parts of the road, the exhaust and thus the environment around the car. An amount of energy also went into accelerating the car from zero velocity to whatever speed it traveled, but most of that eventually went into heat when the car came to a stop.

This is a bit hand wavy of an explanation and we'll learn how to do a better job throughout the quarter. The main point is that we should be able to add all the energy at of the system at the beginning of the process (in all the places it is found) and at the end of the process (in all the places it is found) and those two values should be the same.

6. Identifying and describing mechanism(s) responsible for mediating the transformation of matter and transfer of energy.

Finally, it is useful to try understanding how those transformations of matter and transfers of energy might have been facilitated. For the sake of brevity, in this example we might just say that there was a complicated mechanical device (the engine) that helped facilitate the conversion of matter and transfer of energy about the system and coupled this to the change in position of the car. Someone interested in engines would, of course, give a more detailed explanation.

In this example we made a bunch of simplifying assumptions to highlight the process and to focus on the transformation of the fuel. But that's fine. The more you understand about the processes the finer details you can add. Note that you can use the Energy Story rubric for describing your understanding (or looking for holes in your understanding) of nearly any process (certainly in biology). In BIS2A we'll use the Energy Story to get an understanding of processes as varied as biochemical reactions, DNA replication, the function of molecular motors, etc.

Note:

First: We will be working many examples of the energy story throughout the course - do not feel that you need to have mastery over this topic today.

Second: Nevertheless, while it is tempting to think all this is [superfluous](#) or not [germane](#) to your study of biology in BIS2a, let this serve as a reminder that your instructors (those creating the course midterm and final assessments) view it as core material. We will revisit this topic often throughout the course but need you to get familiar with some of the basic concepts now.

This is important material and an important skill to develop - do not put off studying it because it doesn't "look" like "biology" to you today. The academic term moves VERY quickly and it will be difficult to catch up later if you don't give this some thought now.

Module 01.3

Models and Simplifying Assumptions

Creating Models of Real Things

Life is complicated. To help us understand what we see around us - in both our everyday lives and in science or engineering - we often construct models. A common aphorism states: All models are wrong, but some are

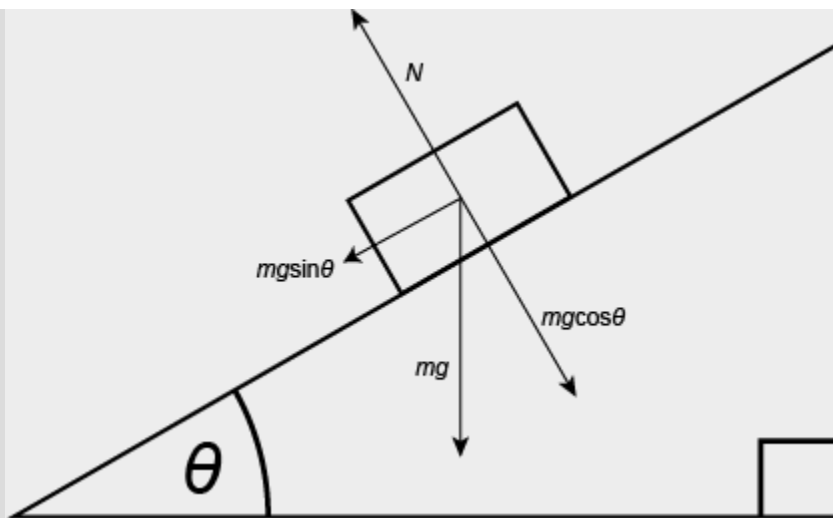
useful. That is, no matter how sophisticated, all models are approximations of something real. While they are not the “real thing” (and are thus wrong), models are useful when they allow us to make predictions about real life that we can use. Models come in a variety of forms that include, but are not limited to:

Types of Models

- Physical models- these are 3D objects that we can touch.
- Drawings - these can be on paper or on the computer and either in 2D or virtual 3D. We mostly look at them.
- Mathematical models - these describe something in real life in mathematical terms. We use these to calculate the behavior of the thing or process we want to understand.
- Verbal or written models - these models are communicated in written or spoken language.
- Mental models - these models are constructed in our minds and we use these to create the other types of models and to understand the things around us.

Usually, in science and everyday life alike, simple models are preferred over complex ones. Creating simple models of complex real things requires us to make what are known as simplifying assumptions. As their name implies, simplifying assumptions are assumptions that are included in the model to simplify the analysis as much as possible. When a simplified model no longer predicts behavior of the real thing within acceptable bounds too many simplifying assumptions have been made. When little predictive value is gained from adding more details to a model, it is likely overly complex. Let's take a look at different types of models and point out their simplifying assumptions. In Physics you will often be asked to create simplified models of real phenomena in which you make simplifying assumptions. For instance, you may be asked to predict how fast a wood block moves down an angled plane under the force of gravity.

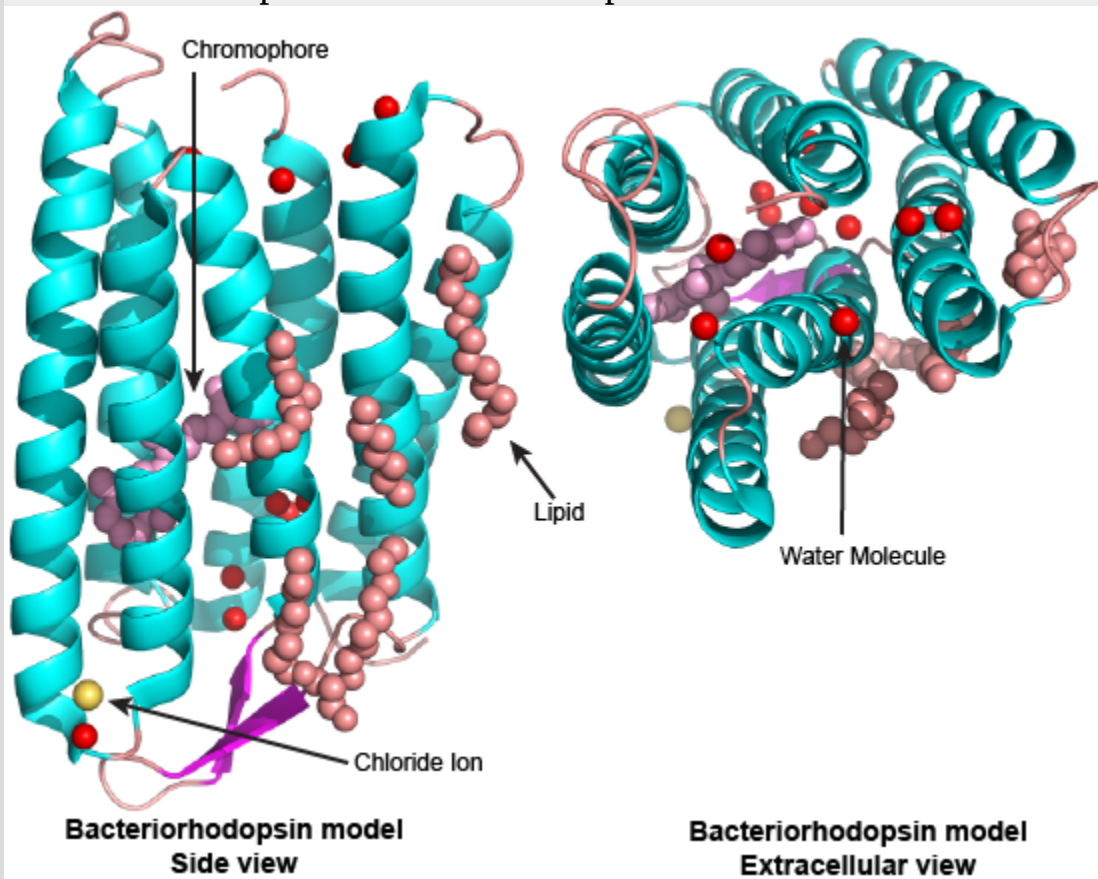
Example: An example from physics: A block on a frictionless plane



A line drawing that models a block (of any material) sitting on a generic incline plane. In this example some simplifying assumptions are made. For instance, the details of the materials the block and plane are made of are ignored. Often we might also for convenience assume that the plane is frictionless. The simplifying assumptions allow the student to practice thinking about how to balance the forces acting on the block when it is elevated in a gravity field and the surface that it is sitting on is not perpendicular to the gravity vector. This simplifies the math and allows the student to focus on the geometry of the model and how to represent that mathematically. The model might do a reasonably good job of predicting the behavior of an ice cube sliding down an glass incline plane but would likely do a bad job of predicting the behavior of a wet sponge on an incline plane coated with sand paper.

Source: Created by Marc T. Facciotti (Own work)

Example: An example from biology: a ribbon diagram of a protein - The transmembrane protein bacteriorhodopsin

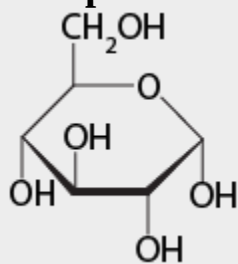


This is a cartoon model of the transmembrane protein bacteriorhodopsin. The protein is represented as a light blue and purple ribbon (the different colors highlight alpha helix and beta sheet, respectively), a chloride ion is represented as a yellow sphere, red spheres represent water molecules, pink ball-and-sticks represent a retinal molecule, and orange ball-and-sticks represent other lipid molecules. The model is displayed in two views. On the left the model is viewed "side

on" while on the right it is viewed along its long axis from the extracellular side of the protein (rotated 90 deg out of the page from the view on the left). This model simplifies many of the atomic-level details of the protein. It also fails to represent the dynamics of the protein. The simplifying assumptions mean that the model would not do a good job predicting the time it takes for the protein to do its work or how many protons can be transported across a membrane per second. On the other hand, this model does a very good job of predicting how much space the protein will take up in a cellular membrane, how far into the membrane the retinal sits, or whether certain compounds can reasonably "leak" through the inner channel.

Source: Created by Marc T. Facciotti (own work), University of California, Davis
Derived from [PDBID:4FPD](#)

Example: An example from Chemistry: A molecular line model of glucose



A line
drawing of
a glucose
molecule.

By

convention,
the points
where
straight
lines meet
are
understood
to represent
carbon
atoms while
other atoms
are shown
explicitly.
Given some
additional
information
about the
nature of
the atoms
that are
figuratively
represented
here, this
model can
be useful
for
predicting
some of the
chemical
properties
of this
molecule,
including
solubility or
the
potential
reactions it

might enter
into with
other
molecules.

The
simplifying
assumption
s however
hide the
dynamics
of the
molecules.

Source:
Created by
Marc T.
Facciotti
(Own work)

Example: An example from everyday life: A scale model of a Ferrari



A scale model of a Ferrari. There are many simplifications and most only make this useful for predicting the general shape and relative proportions of the real thing. For instance, this model gives us no predictive power about how well the car drives or how quickly it stops from a speed of 70 km/s.

Source: Created by Marc T. Facciotti (Own work)

Note: Possible discussion Describe a physical model that you use in everyday life. What does the model simplify from the real thing? *Tip: one person may start a thread by suggesting a model and others may fill in the rest.*

Note: Possible discussion Describe a drawing that you use in science class to model something real. What does the model simplify from the real thing? What are the advantages and disadvantages of the simplifications?

Tip: one person may start a thread by suggesting a model and others may fill in the rest.

The spherical cow

The spherical cow is a famous [metaphor](#) in physics that make fun of physicists tendencies to create hugely simplified models for very complex things. Numerous jokes are associated with this metaphor and they go something like this:

Note: "Milk production at a dairy farm was low, so the farmer wrote to the local university, asking for help from academia. A multidisciplinary team of professors was assembled, headed by a theoretical physicist, and two weeks of intensive on-site investigation took place. The scholars then returned to the university, notebooks crammed with data, where the task of writing the report was left to the team leader. Shortly thereafter the physicist returned to the farm, saying to the farmer, "I have the solution, but it only works in the case of spherical cows in a vacuum"."

Source: Wikipedia page on [Spherical Cow](#) - accessed November 23, 2015.

A Spherical Cow



A cartoon representation of a spherical cow.

Source:

[https://upload.wikimedia.org/wikipedia/commons/d/d2/Sphcow.jp](https://upload.wikimedia.org/wikipedia/commons/d/d2/Sphcow.jpg)

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By Ingrid Kallick (Own work) [GFDL

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(<http://creativecommons.org/licenses/by/3.0>)], via Wikimedia Commons

The spherical cow is an amusing way to ridicule the process of creating simple models and it is quite likely that you will have your BIS2A instructor invoke the reference to the spherical cow when an overly simplified model of something in biology is being discussed. Be ready for it!

Bounding or Asymptotic Analysis

In BIS2A we use models frequently. Sometimes we also like to imagine or test how well our models actually represent reality and compare that with

expectations from what we know to be true for the real life thing. There are many ways to do this depending on how precisely you need to know the behavior of the thing you're trying to model. If you need to know a lot of detail you create a detailed model. If you're willing to live with less detail, you will create a simpler model. In addition to applying simplifying assumptions, it is often useful to assess your model using a technique we call bounding or asymptotic analysis. The main idea of this technique is to use the model, complete with simplifying assumptions, to understand how the real thing might behave at extreme conditions (e.g. evaluate the model at the minimum and maximum values of a variable). Let's examine a simple real life example of how this technique works:

Example: Bounding

Problem setup

Imagine that you need to leave Davis, CA and get home to Selma, CA for the weekend. It's 5PM and you told your parents that you'd be home by 6:30. Selma is 200 miles (322 km) from Davis. You're getting worried that you won't make it home on time. Can you get some estimate of whether it's even possible or if you'll be reheating your dinner in the microwave?

Create Simplified Model and Use of Bounding

You can create a simplified model. In this case you can assume that the road between Davis and Selma is perfectly straight. You also assume that your car has only 2 speeds: 0 mph and 120 mph. These two speeds are the minimum and maximum speeds that you can travel - the bounding values. You can now estimate that even under assumptions of the theoretically "best case" scenario, where you would drive on a perfectly straight road with no obstacles or traffic at maximum speed, you will not make it home on time. At maximum speed you would only cover 180 of the required 200 miles in the 1.5 hours you have.

Interpretation

In this real-life example a simplified model is created. In this case, one very important simplifying assumption is made: The road is assumed to be straight and free of obstacles or traffic. These assumptions allow you to

reasonably assume that you could drive this road at full speed the whole distance. The simplifying assumption simplified out a lot of what you know is actually there in the real world that would influence the speed you could travel and by extension the time it would take to make the trip. The use of bounding – or calculating the behavior of at the minimum and maximum speeds is a way of making quick predictions about what might happen in the real world.

Module 01.4

Evolution and Natural Selection

Evolution and **natural selection** are core concepts in biology that are typically invoked to help explain the diversity of and relationships between life on Earth, both extant and extinct. Fortunately, in BIS2A, you need to understand and use only a few core ideas related to evolution and natural selection. We describe these below. You will expand your understanding and add details to these core concepts in BIS2B and BIS2C.

The first idea you need to grasp is that evolution can be simply defined as the development/change of something over time. In the automotive industry, the shapes and features of cars can be said to evolve (change in time). In fashion, it can be said that style evolves. In biology, life and in particular **reproducing populations** of organisms with **different traits** evolve.

The second thing to understand is that natural selection is a process by which Nature filters organisms in a population. What is the filter? Here it becomes a little more complicated (but only a little). The simplest explanation is that the selective filter is just a combination of all living and non-living factors in an environment, which influence how successfully an organism can reproduce. The factors that influence the ability of an organism to reproduce are known as **selective pressures**. A small but

important complication is that these factors are not the same everywhere and that they change in time and by location. Thus the selective pressures that create the filter are constantly changing (sometimes rapidly, sometimes slowly) and organisms in the same **reproducing population** could experience different pressures at different times and in different locations.

The theory of evolution by natural selection puts these two ideas together; it stipulates that change in biology happens over time and that the variation in a population is constantly subjected to selection based on how differences in traits influence reproduction. But what are these characteristics or **traits**? What traits/features/functions can be subject to selection? The short answer is just about anything associated with an organism for which variation exists in a population and for which this variation leads to a differential likelihood of generating offspring will probably be subject to filtering by natural selection. We also call these traits heritable **phenotypes**. Organisms in a population that have phenotypes, which enable them to pass the selective filter more efficiently than others, are said to have a **selective advantage** and/or **greater fitness**.

It is important to reiterate that while the phenotypes carried by individual organisms may be subject to selection, the process of evolution by natural selection requires and acts on **phenotypic variation** within **populations**. If neither variation nor populations in which that variation can reside exist, there is no opportunity or need for selection. Everything is and stays the same.

Common misconceptions and a course specific note

Finally, we draw your attention to a critical point and common misconception among beginning students in biology. This misconception can arise when, for the sake of discussion, we decide to anthropomorphize Nature by giving it an intellect. For example, we may try to build an example for evolution by natural selection by proposing that a surplus of a particular food exists in an environment and there is an organism close by that is starving. It would be correct to reason that if the organism could eat that food that this might give it a selective advantage over other organisms that cannot. If later we find an example of organisms that have the capability to eat that surplus food it might be tempting to say that Nature

evolved a solution to the problem of eating the surplus food. The process of evolution by natural selection, however, happens randomly and without direction. That is, Nature does NOT identify “problems” that are limiting fitness. Nature does NOT identify features that would make an organism more successful and then start creating diverse solutions that meet this need. The generation of variation is not guided. Variation happens and natural selection filters what works best. The observation that an organism exists that can eat the surplus food is not a reflection of Nature actively solving a problem but rather a reflection that whatever processes that led to phenotypic variation in an ancestral population created – among many other variants – a phenotype that increased fitness (possibly because the ancestral organisms were able to eat the surplus food).

This point of the preceding paragraph is particularly important to understand in the context of BIS2A because of the way we utilizing the Design Challenge to understand biology. While the Design Challenge is intended to help focus our attention on functions under selection and their relationship to determining fitness, it can be easy – if we aren’t attentive – to lapse into language that would suggest that Nature purposefully designs solutions to solve specific problems. Always remember that we are looking retrospectively at what Nature has selected and that we are attempting to understand why a specific phenotype may have been selected from among many other possibilities. In doing so, we will be inferring or hypothesizing to the best of our ability (which is sometimes wrong) a sensible reason for why a phenotype might have provided a selective advantage. We are NOT saying that the phenotype evolved to provide a specific selective advantage. The distinction between these two ideas may be subtle, but it is critical!

Note:

Possible discussion

What physical traits can you think of that gives a selective advantage to certain species? Under what conditions would this trait grant those advantages? Under what conditions might that trait be a selective disadvantage?

Note:

Possible discussion

The great varieties of domesticated dog breeds that we can choose from for companionship are also the result of a process of evolution by selection. Likewise, the development of many very different looking crops - cabbage, brussel sprouts, kohlrabi, kale, broccoli and cauliflower – is also the result of evolution by selection. However, in these two cases the selection or filtering process is referred to **artificial selection** rather than natural selection. Discuss how artificial and natural selection are similar and different?

Note:

Possible discussion

How do environmental and political factors influence manufacturing processes such as auto design? Fashion? Etc. What aspects are similar to the evolution of an organism and what aspects are different?

Note:

Possible discussion

A related but slightly different misconception about evolution by natural selection is that this process leads to the creation the most efficient solutions to problems. What is the problem with this notion?

The importance of knowing key model assumptions

Knowing what simplifying assumptions are made in a model is critical to judging how useful it is for predicting real life and for starting to make a guess about where the model needs improving if it is not sufficiently predictive. In BIS2A you will periodically be asked to create different types of models and to explicitly identify the simplifying assumptions and the impact of those assumptions on the utility and predictive ability of the

model. We will also use models together with bounding exercises to try learning something about the potential behavior of a system.

01.2 The Energy Story

In this module the concepts of Energy and Matter are introduced. The pedagogical rubric called the Energy Story is also explained as a step wise process by which any transformation can be systematically described.

Matter and Energy in Biology

Matter and Energy

The concepts of matter and energy are essential to all scientific disciplines, yet, while ubiquitous and fundamental, these concepts are often amongst the most confounding for students. Take the concept of energy. The term is used in a variety of contexts in everyday life - “Can we move the couch tomorrow? I don’t have the energy.” “Hey dude! Turn the light off. We need to conserve energy.” “This is a great energy drink.” In many sciences classes, students are told that energy comes in different forms (i.e. kinetic, thermal, electrical, potential, etc.), making it difficult to understand exactly what energy “is”. In class, the concept of energy is also associated with a myriad of different equations, each with different variables, but that somehow all seem to end up having units of work. Hold on! Work? I thought we were talking about energy?! Given all the different contexts and sometimes seemingly contradictory treatments and definitions, it’s not hard to understand why these topics seem challenging for many students and in some cases end up turning them off of the fields that make heavy use of these ideas. While the concepts of matter and energy are most often associated with chemistry and physics, they are nevertheless central ideas in biology and we don’t shy away from this in BIS2A. Our instructional goals, however, are to help students develop a conceptual framework that will help them use the concepts of matter and energy to:

- successfully describe biological reactions and transformations;
- create models and hypotheses for “how things work” in biology that explicitly include matter and energy and;
- be scientifically correct and transferable to new problems and to other disciplines.

While there may be a couple of energy-related equations to learn and use in BIS2A, the main focus of the course will be on the robust development of

the concepts of energy and matter and their use in the interpretation of biological [phenomena](#).

Motivation for Learning About Matter and Energy

Discussions about matter and energy make many, but not all, BIS2A students a little apprehensive. After all, aren't these topics that belong in chemistry or physics? However, the transformations of matter and energy transfer are not phenomena reserved for the chemists and physicists or even scientists and engineers more generally. Understanding, conceptualizing, and doing some basic accounting of the transformations of matter and transfers of energy are fundamental skills regardless of occupation or academic training. The scientist may need more rigorous and systematic descriptions of these transformations than the artist but both make use of these skills at various points of their personal and or professional lives. Take the following examples:

Example: Matter and Energy Transformation in Global Warming

Let us for a moment consider a topic that affects us all, global warming. At its core lies a relatively simple model that is based on our understanding of energy in solar radiation, the transfer of this energy with matter on the Earth, and the role and cycling of key carbon containing gases in the Earth's atmosphere. In simple terms solar energy hits the earth and transfers energy to its surface, heating it. Some of this energy is transferred back into space. However, depending on the concentration of carbon dioxide (and other so-called greenhouse gases) different amounts of this energy may become "trapped" in the Earth's atmosphere. Too little carbon dioxide and relatively little energy/heat is trapped - the Earth freezes and becomes inhospitable for life. Too much carbon dioxide and too much heat is trapped - the Earth overheats and becomes inhospitable for life. It stands to reason, therefore, that mechanisms (biological or other) that influence the levels of carbon dioxide in the atmosphere may be important to consider in the story of global warming and that developing a good understanding of global warming phenomena requires one to trace the flow of the carbon and oxygen (matter) through their different forms and the

mechanisms by which energy is transferred to and from different components of the system.

Example: Muscle Contraction

Let us now consider a more personal example, the flexing of an arm starting from an extended position and ending in a flexed position. Like most processes, this one can be described and understood at various levels of detail: from the anatomical point of view where the system consists of muscles, skin, and bones to the molecular where the system is composed of individual interacting biomolecules. At whatever level of detail, if we want to create a story describing this process we know that: (a) the description must include an accounting for what happened to the matter in the system (this includes the change in position of the molecules making up the various parts of the arm and the fuel “burned” to move it) and (b) that some fuel was burned to initiate the movement and therefore, that any description of the process must also include an accounting change in the energy of the system. In simpler terms, this is really just saying that if you want to describe a process where something has happened, you need to describe what happened to the “stuff” in the system and what happened to the energy in the system to make the process happen.

We can't possibly cover all examples of matter and energy transfer in BIS2A. But, we will explore these issues often and practice describing transformations that happen in Nature with a structured and explicit attention to what is happening to the matter and energy in a system as it changes. We will do this exercise across different structural levels in biology, from the molecular level (like a single chemical reaction) to more

large-scale and abstracted models like nutrient cycling in the environment. We will practice this skill by using a [pedagogical](#) tool we call “The Energy Story”. Be prepared to participate!

The Energy Story

Overview of the Energy Story

Whether we know it or not, we tell stories that involve matter and energy everyday, we just don’t often use terminology associated with scientific discussions of matter and energy.

Example:

The setup: a simple statement with implicit details

You tell your roommate a story about how you got to campus by saying, "I biked to campus today". In this simple statement are several assumptions that are instructive to unpack, even if they may not seem very critical to include explicitly in a casual conversation between friends over transportation choices.

An outsider's reinterpretation of the process

To illustrate this, imagine an external observer, for instance an alien being watching the comings and goings of humans on earth. Without the benefit of knowing much of the implied meanings and reasonable assumptions that are buried in our language, the alien's description of the morning cycling trip would be quite different than your own. What you described efficiently as "biking to campus" might be more specifically described by the alien as a change in location of a human body and its bicycle from one location (the apartment, termed position A) to a different location (the university, termed position B). The alien might be even more abstract and describe the bike trip as the movement of matter (the human body and its bike) between an initial state (at location A) to a final state (at location B). Furthermore, from the alien's standpoint what you'd call "biking" might be more specifically described as the use of a two-wheeled tool that couples the

transfer of energy from the electric fields in chemical compounds to the acceleration of the two-wheeled tool-person combo and heat in its environment. Finally, buried within the simple statement describing how we got to work is also the tacit understanding that the mass of the body and bike were conserved in the process (with some important caveats we'll look at in future lectures) and that some energy was converted to enable the movement of the body from position A to position B.

Note:**Possible discussion:** Details are important. What if you owned a fully electric bike and the person you were talking with didn't know that? What important details might this change about the "everyday" story you told that the more detailed description would have cleared up? How would the alien's story have changed? In what scenarios might these changes be relevant?

As this simple story illustrates, irrespective of many factors the process of creating a full description of a process includes some accounting of what happened to the matter, what happened to the energy and almost always some description of a mechanism that describes how changes in matter and energy of a system were brought about.

To practice this skill, in BIS2A we will make use of something we like to call "The Energy Story". You may be asked to tell an energy story in class, to practice telling energy stories on your post or pre lecture study guides, and to use the concept on your exams. In this section, we focus primarily on introducing the concept of an energy story and explaining how to tell one. It is worth noting that the term "energy story" is used almost exclusively in BIS2A (and has a specific meaning in this class). This precise term will not appear in other courses at UC Davis (at least in the short term) or if it appears, is not likely be used in the same manner. You can think of "The Energy Story" as a systematic approach creating a statement or story

describing a biological process or event. Your BIS2A instructors have given this approach a short name "energy story," so that we can all associate it with the common exercise. That way when the instructor asks the class to tell or construct an energy story everyone knows what is meant.

Energy Story

An energy story is a narrative describing a process or event. The critical elements of this narrative are:

1. Identifying at least two states (e.g. start and end) in the process.
2. Identifying and listing the matter in the system and its state at the start and end of the process.
3. Describing the transformation of the matter that occurs during the process.
4. Accounting for the "location" of energy in the system at the start and end of the process.
5. Describing the transfer of energy that happens during the process.
6. Identifying and describing mechanism(s) responsible for mediating the transformation of matter and transfer of energy.

A complete energy story will include a description of the initial reactants and their energetic states as well as a description of the final products and their energetic states after the process or reaction is completed.

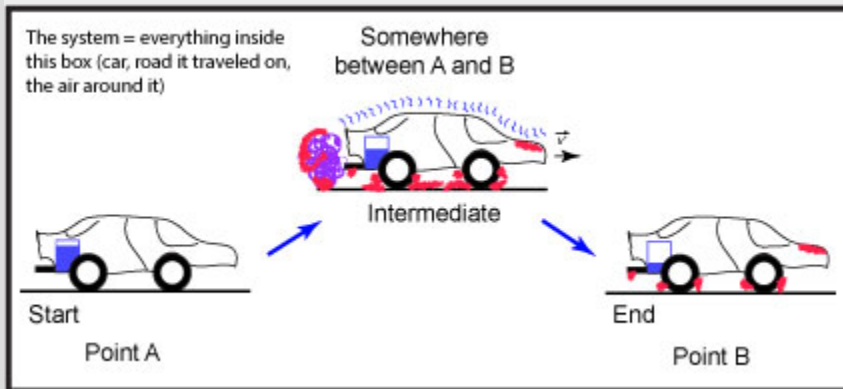
Note:Possible discussion: We argue that the energy story can be used to communicate all of the useful details that are required to describe nearly any process. Can you think of a process that cannot be adequately described by an energy story? If so, describe such a process.

Example:

Energy Story Example

Let us suppose that we are talking about the process of driving a car from "Point A" to "Point B" (see the figure).

A Car Moves from Point A to Point B



A schematic of a car moving at the start from position "Point A" to position "Point B" at the end. The blue rectangle depicted in the back of the car represents the level of gasoline, the purple squiggly line near the exhaust pipe represents the exhaust, squiggly blue lines on top of the car represent sound vibrations and the red shading represents areas that are hotter than at the start.

Source: Created by Marc T. Facciotti (Own work)

Let's step through the Energy Story [rubric](#):

1. Identifying at least two states (e.g. start and end) in the process.

In this example we can easily identify two states. The first state is the non-moving car at "Point A", the start of the trip. The second state, after the process is done, is the non-moving car at "Point B".

2. Identifying and listing the matter in the system and its state at the start and end of the process.

In this case we first note that the "system" includes everything in the figure - the car, the road, the air around the car etc.

It is important to understand the we are going to apply the physical law of conservation of matter. That is, in any of the processes that we will discuss, matter is neither created or destroyed. It might change form, but one should be able to account for everything at the end of a process that was there at the beginning.

At the beginning of the process, the matter in the system consists of:

1. The car and all the stuff in it
2. The fuel in the car (a special thing in the car)
3. The air (including oxygen) around the car.
4. The road
5. The driver

At the end of the process, the matter in the system is distributed as follows:

1. The car and all the stuff in it is in a new place (lets assume, aside from the fuel and position, that nothing else changed)
2. There is less fuel in the car and it too is in a new place
3. The air has changed - it now has less molecular oxygen, more carbon dioxide and more water vapor.
4. The road (let's assume it didn't change - other than a few pebbles moved around)
5. The driver (let's assume she didn't change - though we'll see by the end of the term that she did (at least a little). But, the driver is now in a different place.

3. Describing the transformation of the matter that occurs during the process.

What happened to the matter in this process? Thanks to a lot of simplifying assumptions, we see that two big things happened. First, the car and its driver changed positions - they went from "Point A" to "Point B". Second, we note that the molecules in the fuel, which used to be in the car as a liquid has changed forms and is now mostly in the form of carbon dioxide and water vapor (purple blob coming out the tailpipe). The oxygen molecules that used to be in the air are now also in a new place as part of the carbon dioxide and water that left the car.

4. Accounting for the “location” of energy in the system at the start and end of the process.

It is again important to understand that we are going to invoke the physical law of conservation of energy. That is, we stipulate that the energy in the system cannot be created or destroyed and therefore the energy that is in the system at the start of the process must still be there at the end of the process. It may have been redistributed but you should be able to account for all the energy.

At the beginning of the process, the energy in the system is distributed as follows:

1. The energy tied up in the associations between atoms that make up the matter of the car.
2. The energy tied up in the associations between atoms that make up the fuel.
3. The energy tied up in the associations between atoms that make up the air.
4. The energy tied up in the associations between atoms that make up the road.
5. The energy tied up in the associations between atoms that make up the driver.
6. For all things above we can also say that there is energy in the molecular motions of the atoms that make up the stuff.

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3. The energy tied up in the associations between atoms that make up the air.
4. The energy tied up in the associations between atoms that make up the road.
5. The energy tied up in the associations between atoms that make up the driver.
6. For all things above we can also say that there is energy in the molecular

motions of the atoms that make up the stuff.

This is interesting in some sense because the lists are about the same. We know that the amount of energy stored in the car has decreased because there is less fuel. Something must have happened.

5. Describing the transfer of energy that happens during the process.

In the particular example it is the transfer of energy about the components of the system that is most interesting. As we mentioned, there is less energy stored in the gas tank of the car at the end of the trip because there is now less fuel. We also know intuitively (from our real life experience) that the transfer of energy from the fuel to something else was instrumental in moving the car from "Point A" to "Point B". So, where did this energy go? Remember, it didn't just disappear. It must have moved somewhere else in the system.

Well we know that there is more carbon dioxide and water vapor in the system after the process. There is energy in the associations between those atoms (atoms that used to be in the fuel and air). So some of the energy that was in the fuel is now in the exhaust. Let's also draw from our real life experience again and state that we know that parts of our car have gotten hot by the end of the trip (e.g. the engine, transmission, wheels/tires, exhaust etc.). For the moment we'll just tap our intuition and say that we understand that making something hot involves some transfer of energy. So we can reasonably postulate that some of the energy in the fuel went (directly or indirectly) into heating the car, parts of the road, the exhaust and thus the environment around the car. An amount of energy also went into accelerating the car from zero velocity to whatever speed it traveled, but most of that eventually went into heat when the car came to a stop.

This is a bit hand wavy of an explanation and we'll learn how to do a better job throughout the quarter. The main point is that we should be able to add all the energy at of the system at the beginning of the process (in all the places it is found) and at the end of the process (in all the places it is found) and those two values should be the same.

6. Identifying and describing mechanism(s) responsible for mediating

the transformation of matter and transfer of energy.

Finally, it is useful to try understanding how those transformations of matter and transfers of energy might have been facilitated. For the sake of brevity, in this example we might just say that there was a complicated mechanical device (the engine) that helped facilitate the conversion of matter and transfer of energy about the system and coupled this to the change in position of the car. Someone interested in engines would, of course, give a more detailed explanation.

In this example we made a bunch of simplifying assumptions to highlight the process and to focus on the transformation of the fuel. But that's fine. The more you understand about the processes the finer details you can add. Note that you can use the Energy Story rubric for describing your understanding (or looking for holes in your understanding) of nearly any process (certainly in biology). In BIS2A we'll use the Energy Story to get an understanding of processes as varied as biochemical reactions, DNA replication, the function of molecular motors, etc.

Note:

First: We will be working many examples of the energy story throughout the course - do not feel that you need to have mastery over this topic today.

Second: Nevertheless, while it is tempting to think all this is [superfluous](#) or not [germane](#) to your study of biology in BIS2a, let this serve as a reminder that your instructors (those creating the course midterm and final assessments) view it as core material. We will revisit this topic often throughout the course but need you to get familiar with some of the basic concepts now.

This is important material and an important skill to develop - do not put off studying it because it doesn't "look" like "biology" to you today. The academic term moves VERY quickly and it will be difficult to catch up later if you don't give this some thought now.

01.3 Models, Simplifying Assumptions and Bounding

This module discusses the use of simplifying assumptions and models in science in particular as it applies to the course BIS2A. The module also discusses the use of hypothetical analyses at extreme boundaries.

Models and Simplifying Assumptions

Creating Models of Real Things

Life is complicated. To help us understand what we see around us - in both our everyday lives and in science or engineering - we often construct models. A common aphorism states: All models are wrong, but some are useful. That is, no matter how sophisticated, all models are approximations of something real. While they are not the “real thing” (and are thus wrong), models are useful when they allow us to make predictions about real life that we can use. Models come in a variety of forms that include, but are not limited to:

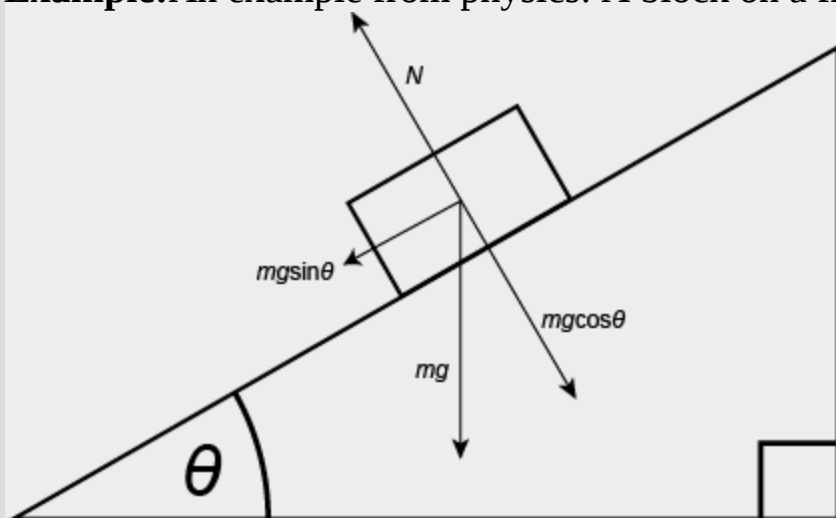
Types of Models

- Physical models- these are 3D objects that we can touch.
- Drawings - these can be on paper or on the computer and either in 2D or virtual 3D. We mostly look at them.
- Mathematical models - these describe something in real life in mathematical terms. We use these to calculate the behavior of the thing or process we want to understand.
- Verbal or written models - these models are communicated in written or spoken language.
- Mental models - these models are constructed in our minds and we use these to create the other types of models and to understand the things around us.

Usually, in science and everyday life alike, simple models are preferred over complex ones. Creating simple models of complex real things requires us to make what are known as simplifying assumptions. As their name implies, simplifying assumptions are assumptions that are included in the model to simplify the analysis as much as possible. When a simplified

model no longer predicts behavior of the real thing within acceptable bounds too many simplifying assumptions have been made. When little predictive value is gained from adding more details to a model, it is likely overly complex. Let's take a look at different types of models and point out their simplifying assumptions. In Physics you will often be asked to create simplified models of real phenomena in which you make simplifying assumptions. For instance, you may be asked to predict how fast a wood block moves down an angled plane under the force of gravity.

Example: An example from physics: A block on a frictionless plane

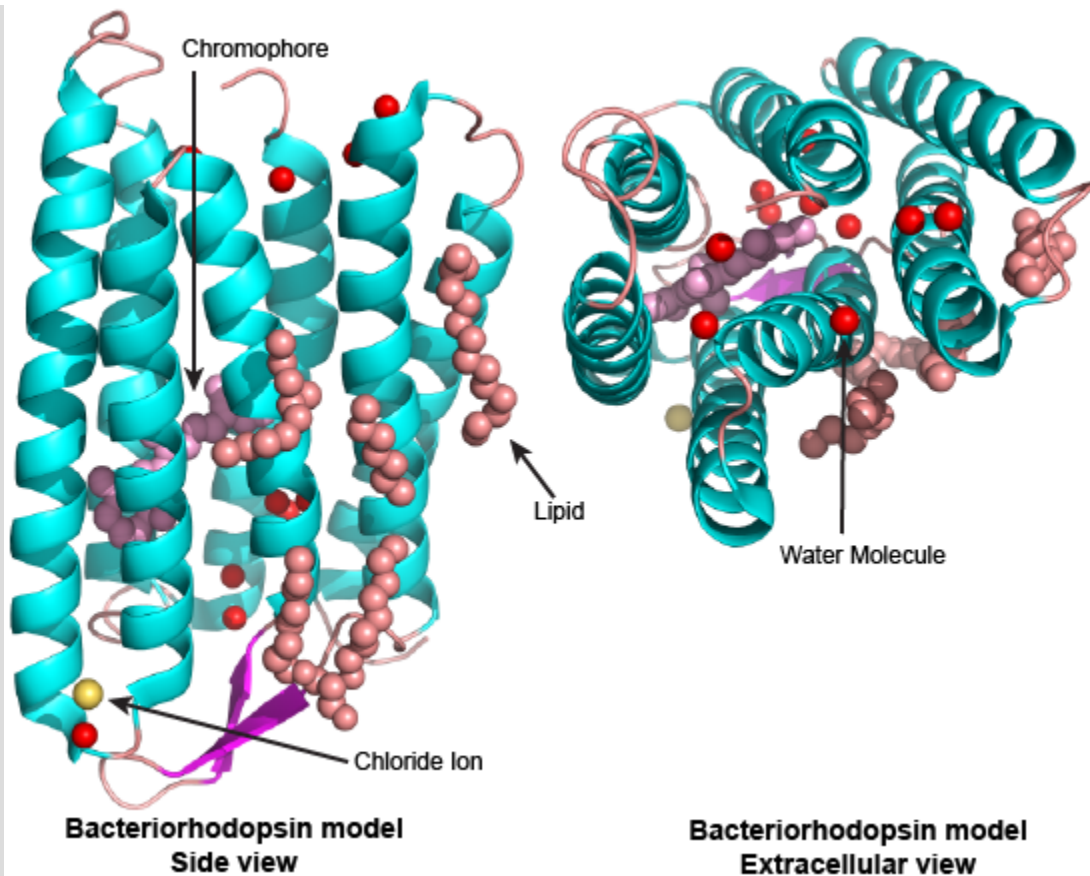


A line drawing that models a block (of any material) sitting on a generic incline plane. In this example some simplifying assumptions are made. For instance, the details of the materials the block and plane are made of are ignored. Often we might also for convenience assume that the plane is frictionless. The simplifying assumptions allow the student to practice thinking about how to balance the forces acting on the block when it is elevated in a gravity field and the surface that it is sitting on is not perpendicular to the gravity vector. This simplifies the math and allows the

student to focus on the geometry of the model and how to represent that mathematically. The model might do a reasonably good job of predicting the behavior of an ice cube sliding down an glass incline plane but would likely do a bad job of predicting the behavior of a wet sponge on an incline plane coated with sand paper.

Source: Created by Marc T. Facciotti (Own work)

Example: An example from biology: a ribbon diagram of a protein - The transmembrane protein bacteriorhodopsin

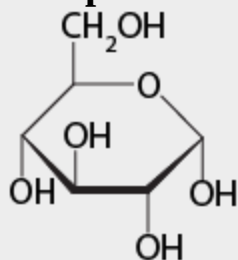


This is a cartoon model of the transmembrane protein bacteriorhodopsin. The protein is represented as a light blue and purple ribbon (the different colors highlight alpha helix and beta sheet, respectively), a chloride ion is represented as a yellow sphere, red spheres represent water molecules, pink balls-and-sticks represent a retinal molecule, and orange balls-and-sticks represent other lipid molecules. The model is displayed in two views. On the left the model is viewed "side on" while on the right it is viewed along its long axis from the extracellular side of the protein (rotated 90 deg out of the page from the view on the left). This model simplifies many of the atomic-level details of the protein. It also fails to represent the dynamics of the protein. The simplifying assumptions mean that the model would not do a good job predicting the time it takes for the protein to do its work or how many protons can be transported across a membrane per second. On the other hand, this model does a very good job of predicting how much space

the protein will take up in a cellular membrane, how far into the membrane the retinal sits, or whether certain compounds can reasonably “leak” through the inner channel.

*Source: Created by Marc T. Facciotti (own work), University of California, Davis
Derived from [PDBID:4FPD](#)*

Example: An example from Chemistry: A molecular line model of glucose



A line drawing of a glucose molecule.

By convention, the points where straight lines meet are understood to represent carbon

atoms while
other atoms
are shown
explicitly.

Given some
additional
information

about the
nature of
the atoms
that are

figuratively
represented

here, this
model can
be useful

for
predicting
some of the

chemical
properties
of this

molecule,
including

solubility or
the

potential
reactions it
might enter

into with
other
molecules.

The
simplifying
assumption
s however
hide the

dynamics
of the
molecules.

*Source:
Created by
Marc T.
Facciotti
(Own work)*

Example: An example from everyday life: A scale model of a Ferrari



A scale model of a Ferrari. There are many simplifications and most only make this useful for predicting the general shape and relative proportions of the real thing. For instance, this model gives us no predictive power about

how well the car drives or how quickly it stops from a speed of 70 km/s.

Source: Created by Marc T. Facciotti (Own work)

Note: Possible discussion Describe a physical model that you use in everyday life. What does the model simplify from the real thing? *Tip: one person may start a thread by suggesting a model and others may fill in the rest.*

Note: Possible discussion Describe a drawing that you use in science class to model something real. What does the model simplify from the real thing? What are the advantages and disadvantages of the simplifications? *Tip: one person may start a thread by suggesting a model and others may fill in the rest.*

The spherical cow

The spherical cow is a famous [metaphor](#) in physics that make fun of physicists tendencies to create hugely simplified models for very complex things. Numerous jokes are associated with this metaphor and they go something like this:

Note: "Milk production at a dairy farm was low, so the farmer wrote to the local university, asking for help from academia. A multidisciplinary team of professors was assembled, headed by a theoretical physicist, and two weeks of intensive on-site investigation took place. The scholars then returned to the university, notebooks crammed with data, where the task of writing the report was left to the team leader. Shortly thereafter the physicist returned to the farm, saying to the farmer, "I have the solution, but it only works in the case of spherical cows in a vacuum"."

Source: Wikipedia page on [Spherical Cow](#) - accessed November 23, 2015.

A Spherical Cow



A cartoon representation of a spherical cow.

Source:

[https://upload.wikimedia.org/wikipedia/commons/d/d2/Sphcow.jp](https://upload.wikimedia.org/wikipedia/commons/d/d2/Sphcow.jpg)

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The spherical cow is an amusing way to ridicule the process of creating simple models and it is quite likely that you will have your BIS2A instructor invoke the reference to the spherical cow when an overly simplified model of something in biology is being discussed. Be ready for it!

Bounding or Asymptotic Analysis

In BIS2A we use models frequently. Sometimes we also like to imagine or test how well our models actually represent reality and compare that with expectations from what we know to be true for the real life thing. There are many ways to do this depending on how precisely you need to know the behavior of the thing you're trying to model. If you need to know a lot of detail you create a detailed model. If you're willing to live with less detail, you will create a simpler model. In addition to applying simplifying assumptions, it is often useful to assess your model using a technique we call bounding or asymptotic analysis. The main idea of this technique is to use the model, complete with simplifying assumptions, to understand how the real thing might behave at extreme conditions (e.g. evaluate the model at the minimum and maximum values of a variable). Let's examine a simple real life example of how this technique works:

Example: Bounding

Problem setup

Imagine that you need to leave Davis, CA and get home to Selma, CA for the weekend. It's 5PM and you told your parents that you'd be home by 6:30. Selma is 200 miles (322 km) from Davis. You're getting worried that you won't make it home on time. Can you get some estimate of whether it's even possible or if you'll be reheating your dinner in the microwave?

Create Simplified Model and Use of Bounding

You can create a simplified model. In this case you can assume that the road between Davis and Selma is perfectly straight. You also assume that your car has only 2 speeds: 0 mph and 120 mph. These two speeds are the minimum and maximum speeds that you can travel - the bounding values. You can now estimate that even under assumptions of the theoretically "best case" scenario, where you would drive on a perfectly straight road with no obstacles or traffic at maximum speed, you will not make it home on time. At maximum speed you would only cover 180 of the required 200 miles in the 1.5 hours you have.

Interpretation

In this real-life example a simplified model is created. In this case, one very important simplifying assumption is made: The road is assumed to be straight and free of obstacles or traffic. These assumptions allow you to reasonably assume that you could drive this road at full speed the whole distance. The simplifying assumption simplified out a lot of what you know is actually there in the real world that would influence the speed you could travel and by extension the time it would take to make the trip. The use of bounding – or calculating the behavior of at the minimum and maximum speeds is a way of making quick predictions about what might happen in the real world.

The importance of knowing key model assumptions

Knowing what simplifying assumptions are made in a model is critical to judging how useful it is for predicting real life and for starting to make a guess about where the model needs improving if it is not sufficiently predictive. In BIS2A you will periodically be asked to create different types of models and to explicitly identify the simplifying assumptions and the impact of those assumptions on the utility and predictive ability of the model. We will also use models together with bounding exercises to try learning something about the potential behavior of a system.

01.4 Evolution and Natural Selection

This module provides a very brief introduction to the concepts of evolution and natural selection for students in BIS2A. At this point in the course, the material is intended to provide a context for some of the exercises used in BIS2A; this is not intended to be a detailed description. These basic concepts will be expanded upon later in the class and in subsequent courses.

Evolution and Natural Selection

Evolution and **natural selection** are core concepts in biology that are typically invoked to help explain the diversity of and relationships between life on Earth, both extant and extinct. Fortunately, in BIS2A, you need to understand and use only a few core ideas related to evolution and natural selection. We describe these below. You will expand your understanding and add details to these core concepts in BIS2B and BIS2C.

The first idea you need to grasp is that evolution can be simply defined as the development/change of something over time. In the automotive industry, the shapes and features of cars can be said to evolve (change in time). In fashion, it can be said that style evolves. In biology, life and in particular **reproducing populations** of organisms with **different traits** evolve.

The second thing to understand is that natural selection is a process by which Nature filters organisms in a population. What is the filter? Here it becomes a little more complicated (but only a little). The simplest explanation is that the selective filter is just a combination of all living and non-living factors in an environment, which influence how successfully an organism can reproduce. The factors that influence the ability of an organism to reproduce are known as **selective pressures**. A small but important complication is that these factors are not the same everywhere and that they change in time and by location. Thus the selective pressures that create the filter are constantly changing (sometimes rapidly, sometimes slowly) and organisms in the same **reproducing population** could experience different pressures at different times and in different locations.

The theory of evolution by natural selection puts these two ideas together; it stipulates that change in biology happens over time and that the variation in

a population is constantly subjected to selection based on how differences in traits influence reproduction. But what are these characteristics or **traits**? What traits/features/functions can be subject to selection? The short answer is just about anything associated with an organism for which variation exists in a population and for which this variation leads to a differential likelihood of generating offspring will probably be subject to filtering by natural selection. We also call these traits heritable **phenotypes**. Organisms in a population that have phenotypes, which enable them to pass the selective filter more efficiently than others, are said to have a **selective advantage** and/or **greater fitness**.

It is important to reiterate that while the phenotypes carried by individual organisms may be subject to selection, the process of evolution by natural selection requires and acts on **phenotypic variation** within **populations**. If neither variation nor populations in which that variation can reside exist, there is no opportunity or need for selection. Everything is and stays the same.

Common misconceptions and a course specific note

Finally, we draw your attention to a critical point and common misconception among beginning students in biology. This misconception can arise when, for the sake of discussion, we decide to anthropomorphize Nature by giving it an intellect. For example, we may try to build an example for evolution by natural selection by proposing that a surplus of a particular food exists in an environment and there is an organism close by that is starving. It would be correct to reason that if the organism could eat that food that this might give it a selective advantage over other organisms that cannot. If later we find an example of organisms that have the capability to eat that surplus food it might be tempting to say that Nature evolved a solution to the problem of eating the surplus food. The process of evolution by natural selection, however, happens randomly and without direction. That is, Nature does NOT identify “problems” that are limiting fitness. Nature does NOT identify features that would make an organism more successful and then start creating diverse solutions that meet this need. The generation of variation is not guided. Variation happens and natural selection filters what works best. The observation that an organism exists that can eat the surplus food is not a reflection of Nature actively

solving a problem but rather a reflection that whatever processes that led to phenotypic variation in an ancestral population created – among many other variants – a phenotype that increased fitness (possibly because the ancestral organisms were able to eat the surplus food).

This point of the preceding paragraph is particularly important to understand in the context of BIS2A because of the way we utilizing the Design Challenge to understand biology. While the Design Challenge is intended to help focus our attention on functions under selection and their relationship to determining fitness, it can be easy – if we aren't attentive – to lapse into language that would suggest that Nature purposefully designs solutions to solve specific problems. Always remember that we are looking retrospectively at what Nature has selected and that we are attempting to understand why a specific phenotype may have been selected from among many other possibilities. In doing so, we will be inferring or hypothesizing to the best of our ability (which is sometimes wrong) a sensible reason for why a phenotype might have provided a selective advantage. We are NOT saying that the phenotype evolved to provide a specific selective advantage. The distinction between these two ideas may be subtle, but it is critical!

Note:

Possible discussion

What physical traits can you think of that gives a selective advantage to certain species? Under what conditions would this trait grant those advantages? Under what conditions might that trait be a selective disadvantage?

Note:

Possible discussion

The great varieties of domesticated dog breeds that we can choose from for companionship are also the result of a process of evolution by selection. Likewise, the development of many very different looking crops - cabbage, brussel sprouts, kohlrabi, kale, broccoli and cauliflower – is also the result

of evolution by selection. However, in these two cases the selection or filtering process is referred to **artificial selection** rather than natural selection. Discuss how artificial and natural selection are similar and different?

Note:

Possible discussion

How do environmental and political factors influence manufacturing processes such as auto design? Fashion? Etc. What aspects are similar to the evolution of an organism and what aspects are different?

Note:

Possible discussion

A related but slightly different misconception about evolution by natural selection is that this process leads to the creation the most efficient solutions to problems. What is the problem with this notion?